Department of
Mathematical Sciences

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

AIMS
SOUTH AFRICA

BSc (Honours) in Mathematics

with focus in

Biomathematics

Information 2014

Biomathematics Postgraduate Programme

(Honours, Masters, PhD)

There are **three key ingredients** making the Biomathematics postgraduate programme attractive and unique:

- Firstly, the exposure, through leading local and international experts, to various perspectives driving the needed coalescence between mathematics and biology/medicine.
- Secondly, the study of a wide range of mathematical, statistical and computational techniques useful for addressing problems and challenges from the biological, medical and/or environmental sciences.
- Thirdly, the interdisciplinary nature involving collaborative project work with researchers in mathematical sciences and in biological/biomedical sciences.

Offerings

In 2008 the Biomathematics stream of the BSc (with Molecular or Ecology options) was introduced at the University of Stellenbosch – the first such stream at a South African university. From 2009 a new focus in Biomathematics of the BSc (Honours) in Mathematics was introduced as a degree of the University of Stellenbosch and offered by the Department of Mathematical Sciences and the African Institute for Mathematical Sciences (AIMS). Masters and doctoral studies in biomathematics typically involves co-supervision by a biomathematician and biological/biomedical scientist.

Admission requirements

For the Biomathematics focus of the BSc (Honours) in Mathematics, high academic achievement in a BSc, with a major in Mathematical Sciences and preferably some courses in a biological/biomedical field, or an equivalent qualification. For Masters in Mathematics with focus in Biomathematics, a suitable BSc (Honours) degree, or an equivalent qualification that has been approved by the Senate.

Postgraduate studies application procedure and deadlines

The postgraduate studies application procedure and form is available via the Science Faculty webpage at http://science.sun.ac.za/ under Information for Students, Postgraduate Programmes. Applications should reach the Registrar or the Departmental Chairperson by the end of October of the previous year.

Funding opportunities

- **DST/NRF Innovation Honours** bursaries of R35 000 for 1 year.
- **DST/NRF Innovation Masters** scholarships of R60 000 per annum for 2 years. Plus a once-off allocation of R10 000 for conference attendance or a study visit.
- **DST/NRF Innovation Doctoral** scholarships of R90 000 per annum for 3 years. Plus up to R40 000 for international study visits or conference presentations.
- **SACEMA Honours** Bursary of R25 000 for 1 year.
- **Stellenbosch University postgraduate funding** opportunities of variable amounts, some of which may not be held concurrently with the above bursaries. Please refer to the Stellenbosch University website http://www0.sun.ac.za/pgstudies/postgraduate-student-funding.html

DST/NRF Funding application procedure and deadlines

Please note that the DST/NRF honours bursaries and masters scholarships are only available to South African students.

For the Honours bursary, the attached form (together with supporting documentation) should be completed and submitted to

Prof Ingrid Rewitzky by **end of September of year preceeding study**

For the Masters/Doctoral scholarships, the form available via the NRF online system at http://www.nrf.ac.za/studentsupport/ should be submitted electronically via that system by **31 July of year preceeding study.**

Employment opportunities

Students with the skills gained from this course will be readily employed by biotechnology companies, pharmaceutical companies, academic and research institutions. Work may involve fundamental scientific research and/or diverse applications including: drug design, immunology and medical applications, forensics, and molecular evolution and population biology.

Contacts:

First semester 2014:

- Prof Ingrid Rewitzky, Executive Head of Mathematical Sciences (Email: rewitzky@sun.ac.za)

Second semester 2014:

- Prof Farai Nyabadza, the Biomathematics Program Coordinator (Email: nyabadzaf@sun.ac.za)

Biomathematics Focus of the BSc (Honours) in Mathematics

Timetable

Date	Module Name	Lecturer	Module Code
20-24 January	Intro to Computing and Latex	Groenewald	747
27 Jan – 14 Feb	Programing with Python and Heuristic Search	Meseguer, Ocansey	747
27 Jan – 14 Feb	Mathematical Modelling in Biosciences	Kostur	723
27 Jan – 14 Feb	Analytical Techniques in Mathematical Biology	Lamb	724
27 Jan – 14 Feb	Mathematical Modelling in Biology	Ouhinou	748 (1)
17 March – 4 April	Epidemiology of Infectious Diseases	Mugwagwa, Lutambi	748 (2)
17 March – 4 April	Computational Biology	Jacobson	725
14 April – 2 May	Systems Biology	Uys	721
5 May to 13 June	Modelling Neural Systems	Orchard	747
2 – 13 June	MMED	Pulliam	726
21 July - 24 October	Non-linear Dynamical Systems in Biomathematics	Nyabadza	722
21 July – 24 October	Elective module	Various	
1 June – 14 Nov	Project	Various	747

Biomathematics Focus of the BSc (Honours) in Mathematics

Modules

All modules must be completed and passed with at least 50% in order for the degree to be completed and awarded by Stellenbosch University.

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721. **Computational and discrete methods in Biomathematics** (16 credits)

Systems Biology

Dr Lafras Uys, AIMS

14 April to 2 May

The Systems Biology course will focus on enzyme kinetics, metabolic networks and homoeostatic control in these networks. The necessary chemistry and biology will be covered, followed by the mathematical approaches to model these systems. The enzyme kinetics component of the course will deal with classical methods of modelling reaction rates in catalysis. This includes the so-called Michaelis-Menten and Monod-Wyman-Changeux kinetics. More modern methods of modelling reaction rates, such as Generic Reversible Hill equations, will also be covered. The second part of the course will deal with systems of enzyme-catalysed, coupled reactions. We will study at least two methods of analysing these models, namely Supply-Demand Analysis and Metabolic Control Analysis. If time permits we may give an overview of current areas of research in Systems Biology, such as the use of algebraic geometry in modelling metabolic networks.

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722. **Non-linear dynamical systems in Biomathematics** (16 credits)

Prof Farai Nyabadza, Stellenbosch University,

21 July to 24 October

The goal of the course is to introduce students to dynamical systems that arise in Biomathematics. The intention is to look at **dynamical systems** as the study of the long-term behavior of evolving systems. We focus specifically on non-linear models of epidemics and models arising from ecology. Analysis of non-linear systems and their properties will be looked at. Topics include bifurcations, stability theory, Lyapnuov functions. The derivations of Lyapunov functions for epidemic models are given as examples. Students will be given the opportunity to develop non-linear models of their choice, use techniques learnt during lecture times to analyse their models.

723. **Advanced topics in Biomathematics I** (8 credits)

Mathematical Modelling in Biosciences

Dr Marcin Kostur, Silesia

27 January to 14 February

This course will contain applications of differential equations, partial differential equations and stochastic differential equation to biology, chemistry, and physics. The approach will emphasis numerical solutions to particular problems, however the classical analytical solutions to various models will be also presented. The goal of this course, apart of presenting several examples of mathematical modelling, will be to build up the student's intuition by numerical experimentation. All modelling will be done in Sage, if necessary external libraries as scipy for sparse numerical algebra will be applied. It is possible, for more advanced students to use GPU/CUDA computing for solving most of those problems (PDE and SDE).

724. **Advanced topics in Biomathematics II** (8 credits)

Analytical Techniques in Mathematical Biology

Dr Wilson Lamb, Strathclyde

27 January to 14 February

Mathematical models arising in the natural sciences often involve equations which describe how the phenomena under investigation evolve in time. When time is regarded as a continuous variable such evolution equations usually take the form of differential equations. In this course a number of mathematical techniques will be presented for analysing a range of evolution equations that arise in Biomathematics, particularly in population dynamics. The emphasis will be placed on determining qualitative features of solutions, such as the long-term behaviour. Different types of equations will be examined, but a unifying theme will be provided by developing methods from a dynamical systems point of view and using some results from functional analysis. To fix ideas, the course will begin with some simple one-dimensional models from population dynamics, such as the Malthusian and Verhulst equations. Structured population models arising in epidemiology, such as the SIS and SIR models, and multispecies models, such as the Lotka –Volterra predator-prey equations, will be considered next. The latter models result in non-linear systems of ordinary differential equations and their analysis involves higher (but still finite) dimensional dynamical systems theory. To give an indication of the need, in some problems, to work within an infinite-dimensional setting, we shall conclude by examining the notion of diffusion-driven (or Turing) instability in reaction-diffusion type partial differential equations and discuss mathematical models of pattern formation (e.g. in animal coats) that involve such equations.

725. **Topics in Biological Sciences** (8 credits)

Computational Biology

Dr Dan Jacobson, Stellenbosch University

17 March to 4 April

The aim of this course is to expose the students to different methods and data types encountered in computational biology. This course will look at a selection of computational techniques and metrics in genomic, phylogenomic and transcriptomic studies, with an emphasis on techniques related to network theory.

The following topics will be covered in class:

- **Detecting Novel Associations in Large Datasets**
  A new metric, the Maximum Information Coefficient is introduced, which is can detect non-linear relationships between variables or samples in a biological dataset.
- **An Efficient Algorithm for Large-scale Detection of Protein Families**
  The Markov Cluster Algorithm is introduced as a network clustering algorithm and applied to a protein-similarity network, producing gene families in a process called TribeMCL.
- **Weighted Gene Coexpression Network Analysis: State of the Art**
  A number of network theory measures are discussed, and a clustering algorithm based on the Topological Overlap between nodes is introduced. Examples of the use of this clustering algorithm in the analysis of gene coexpression networks are discussed.
- **Comparative Gene Coexpression Analysis**
  We will outline the procedure for comparing gene coexpression networks across species.
- **The inference of protein-protein interactions by co-evolutionary analysis is improved by excluding the information about the phylogenetic relationships**
  An adaptation to the mirror tree method is described, in which quantifying gene coevolution by calculating the correlation between the evolutionary histories of genes (based on substitution models) allows protein-protein interactions to be predicted.

Classes are conducted in a different manner than usual lectures. Each evening, students are given a journal article to read and understand as much as possible that evening. They are instructed to compose 5 multiple choice questions related to the content of the article and hand them in before the next class. In class, we will then discuss the article, go through what was not understood and also answer multiple choice questions created by the students. Students are encouraged to engage in class discussions with the lecturers and with each other, discussing the questions being asked and explaining/arguing their views. This method of teaching encourages students to engage with the material before and during class, instead of sit passively in a formal lecture where they might or might not understand or try to understand the material.

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726. **Topics in Biomedical Sciences** (8 credits)

Mathematical Modeling in Medicine and Public Health

Juliet Pulliam, Fogarty International Center, U.S. National Institutes of Health

Steve Bellan, University of California – Berkeley

2 to 13 June

Addressing applied problems with mathematical models is most useful when these models are closely linked to relevant data. This course will focus on models of infectious disease dynamics and methods for linking models and data. The course will occur in three parts. During the first week, students will be introduced to biological and epidemiological aspects of infectious diseases and will learn how these considerations are related to infectious disease models. Students will also develop ideas for research projects that bring together data and modeling to address an applied question in infectious disease epidemiology. In the second and third weeks, students will participate in the Clinic on the Meaningful Modeling of Epidemiological Data (MMED, http://lalahsan.mcmaster.ca/theobio/mmed), an interactive workshop that brings together students and researchers from Africa and North America to learn about data-driven infectious disease modeling and how it fits within the broader discipline of public health. Biomathematics students participate fully in this workshop and will give oral presentations of their research project proposals at the MMED Clinic. Finally, students will complete written projects in which they carry out their proposed research plan.

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749. **Advanced topics in Biomathematics IV** (8 credits)

Modelling Neural Systems

Dr Jeff Orchard, Waterloo

5 May to 13 June

This course is intended to give students an overview of neuroscience and quantitative approaches to understanding how the brain works. Topics include:

1. Neuron models
2. Populations of neurons
3. Learning algorithms
4. Neural systems Mathematical and computational models will be explored using free software.

748. **Advanced topics in Biomathematics III Part 1** (8 credits)

Mathematical Modelling in Biology

Dr Aziz Ouhinou, Soultan Moulaye Slimane

24 February to 14 March

The aim of the course is to show techniques through different applications in different area. This will include mathematical modeling, the focus will be more on ordinary and partial differential equations, with some time delay odes.

Section 1: An overview on dynamical systems. (2 hours) Steady states and their stability Principal of linearisation Poincare-bendixon theorem

Section 2: Continuous population models (8 hours) Single species, insect outbreak model. Modeling two interacting populations Modelling harvesting of a population. Kinetic models, law of mass action. The aspect of slow and fast variables

Section 3: Delay models with application in biology, aspect of periodic dynamics. (Application in physiology and Haematopoiesis). (4 hours)

Section 4: Spatio-temporal models (8 hours) Reaction diffusion in biology. Chemotaxis in biology. Wave solution and their applications in biology. Application to spread of rabies.

Section 5: Pattern formation: (4 hours) Diffusion-driven instability. Minimum domain size for pattern formation in a single reaction-diffusion equation.

Section 6: Mathematical modeling of solid tumour growth. (4 hours)

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748. **Advanced topics in Biomathematics III Part 2** (8 credits)

Epidemiology of Infectious Diseases

Tendai Mugwagwa (Imperial College)

Angeline Lutambi (Ifakara Health Institute)

17 March to 4 April

By the end of the course we hope the students will have a broad view of the field of mathematical epidemiology and its importance for research and public health decision making. Students should have an understanding of how their current mathematical skills can be used to solve different epidemiological problems. Ideally they will be able to translate epidemiological problems into mathematical problems, solve them analytically or through simulations and interpret the results in relation to the original problem.

General course content.

1- Basic mathematical models of infection disease dynamics.
2- Analytical and simulation methods for epidemiological models.
3- Parameter estimation, model calibration and validation.
4- Examples of epidemiology models (Tuberculosis, Malaria, Measles, Influenza, HIV and other Sexually transmitted diseases).
5- Identification and evaluation of public health intervention policies.

Learning Methods Lectures, exercises, computer practical work, group discussions, and project work.

Assessment of student performance during the course will be through individual assignments and a group project which includes a presentation of results to the rest of the class.

Elective module (8 credits)

A second semester honours module offered in the Department of Mathematical Sciences subject to the approval of the biomathematics coordinator.

Kindly refer to the following websites for options:

- Mathematics: http://math.sun.ac.za/honours/
- Applied Mathematics: http://dip.sun.ac.za/new_webpage/Postgrad.html

747. **Honours project: Biomathematics - Research Methods** (8 credits)

Introduction to Computing and Latex

Jan Groenewald, AIMS

20 – 24 January

This course introduces the students to the AIMS computing facilities and packages. The course covers an introduction to LaTeX using texmaker, followed by working through the book: http://en.wikibooks.org/wiki/ LaTeX , and associated documents such as those from the American Mathematical Society

Programming with Python and Heuristic Search

Pedro Meseguer (CSISC) and Evans Ocansey (AIMS)

27 January to 14 February

This course on Heuristic Search describes a quite general problem solving method based on the exploration of search spaces. This method is of great interest for the effective solution of difficult problems (such as the Rubik's cube, travelling salesman, number partitioning, to name a few) which have to be solved combining the different alternatives that can be used to achieve a solution. Often, these problems have an optimization version. A specific item on Computer Chess is included, to deal with a hot topic particularly popular after the defeat of the world championship by the computer Deep Blue in 1997.

This course follows a Computer Science approach. Motivated by a number of difficult problems (many of them of mathematical nature), the course considers how to achieve their effective solution by using a computer. The course includes the algorithms for the exploration of search spaces, and it will consider their implementation using the Python programming language.

This course can be of interest for mathematicians, computer scientists, or engineers willing to deepen their knowledge in the effective resolution of difficult problems by systematic exploration of their search spaces using computers.

Research Seminar or Journal Club
21 July to 24 October

Details will be provided by Prof Farai Nyabadza in July.

747. **Honours project: Biomathematics - Research Project** (24 credits)

21 July to 24 October

A research topic, co-supervised by a biomathematician and a biological/biomedical scientist, will involve the application of mathematical, computational and statistical methods to analyse and solve a problem in biological sciences, environmental sciences or medical sciences. The report should consist of:

- Statement of the biological/medical problem
- Description of the mathematical approach
- Model formulation and justification
- Parameter estimation and simulation
- Mathematical analysis
- Implications, limitations and future directions.